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(54) Electromagnetic alignment and scanning apparatus

(57) An apparatus capable of high accuracy position and motion control is disclosed and utilizes one or more linear commutated motors (54A, 54B, Fig. 5, not shown) to move a guideless stage (14) in one long linear direction and a small rotation in a plane. A carrier/follower (60) holding a single voice coil motor (VCM) (70) is controlled to approximately follow the stage in the direction of the linear motion. The VCM provides an electro-magnetic force to move the stage for small displacements in the plane in a linear direction perpendicular to the direction of the linear motion to ensure proper alignment. One element of the linear commutated motors is mounted on a freely suspended drive assembly frame (22) which is moved in the opposite direction to that of the stage by a reaction force to maintain the center of gravity of the apparatus.

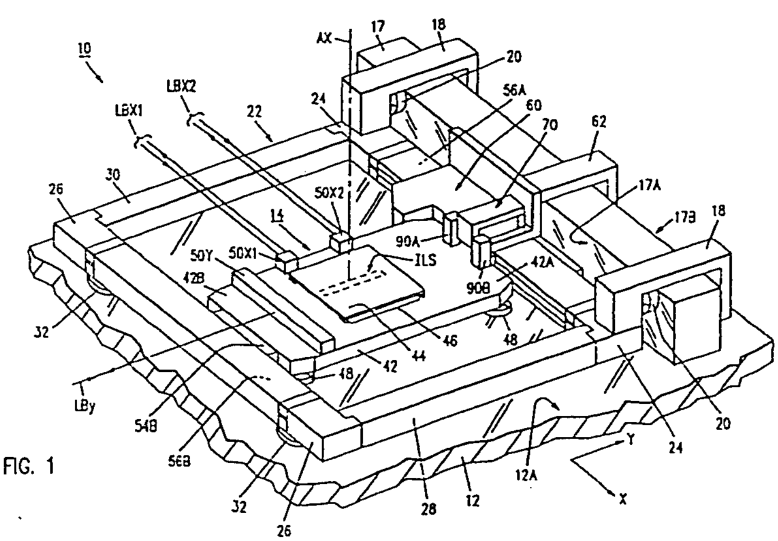


FIG. 1

GB 2 290 658 A

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

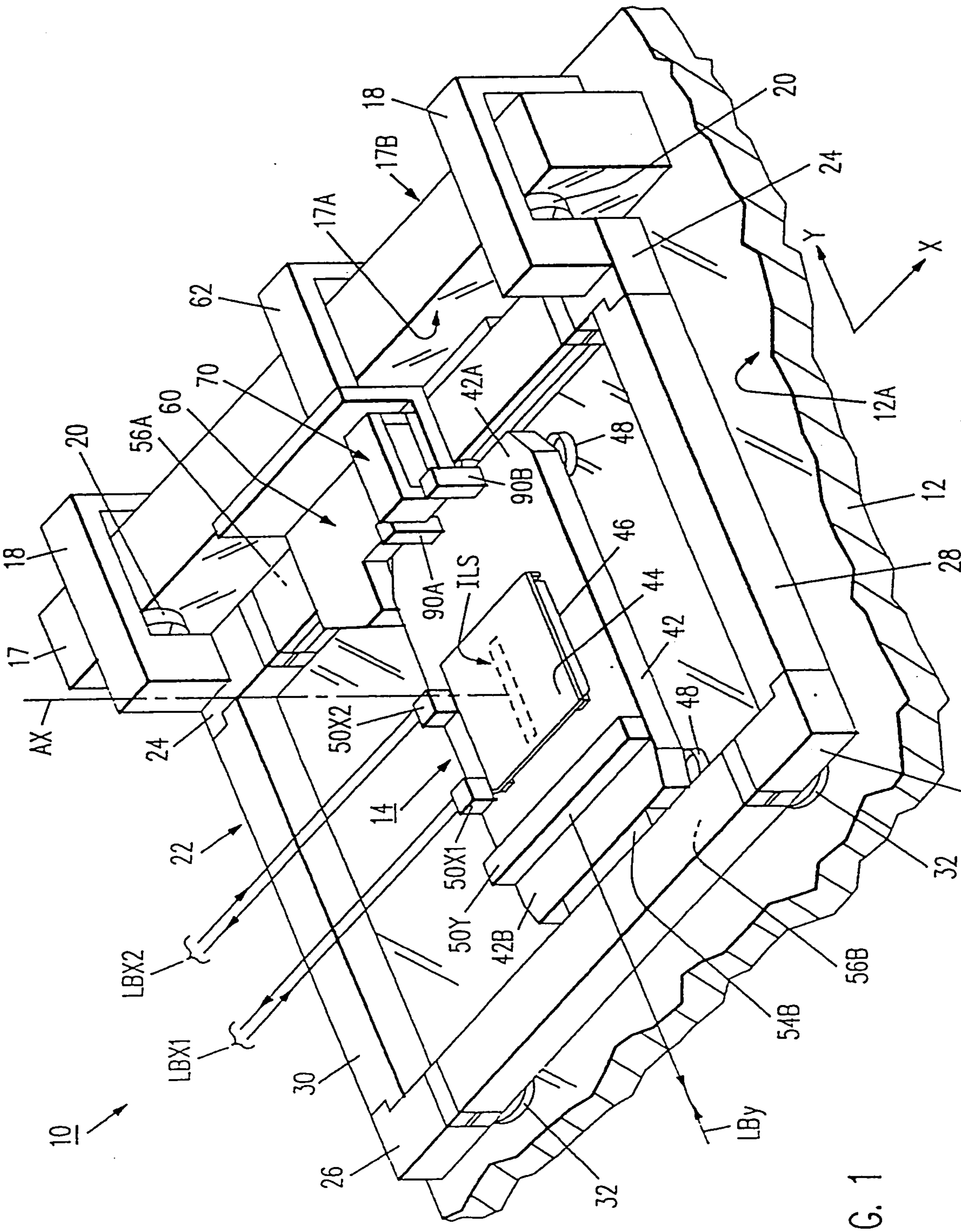

10
AX
17
18
20
24
22
LBX2
LBX1
30
26
32
56A
60
70
62
17A
17B
18
20
24
Y
X
12A
12
28
26
32
42A
90B
90A
ILS
48
46
44
42
48
50X2
14
50X1
50Y
42B
54B
56B
LBy

FIG. 1

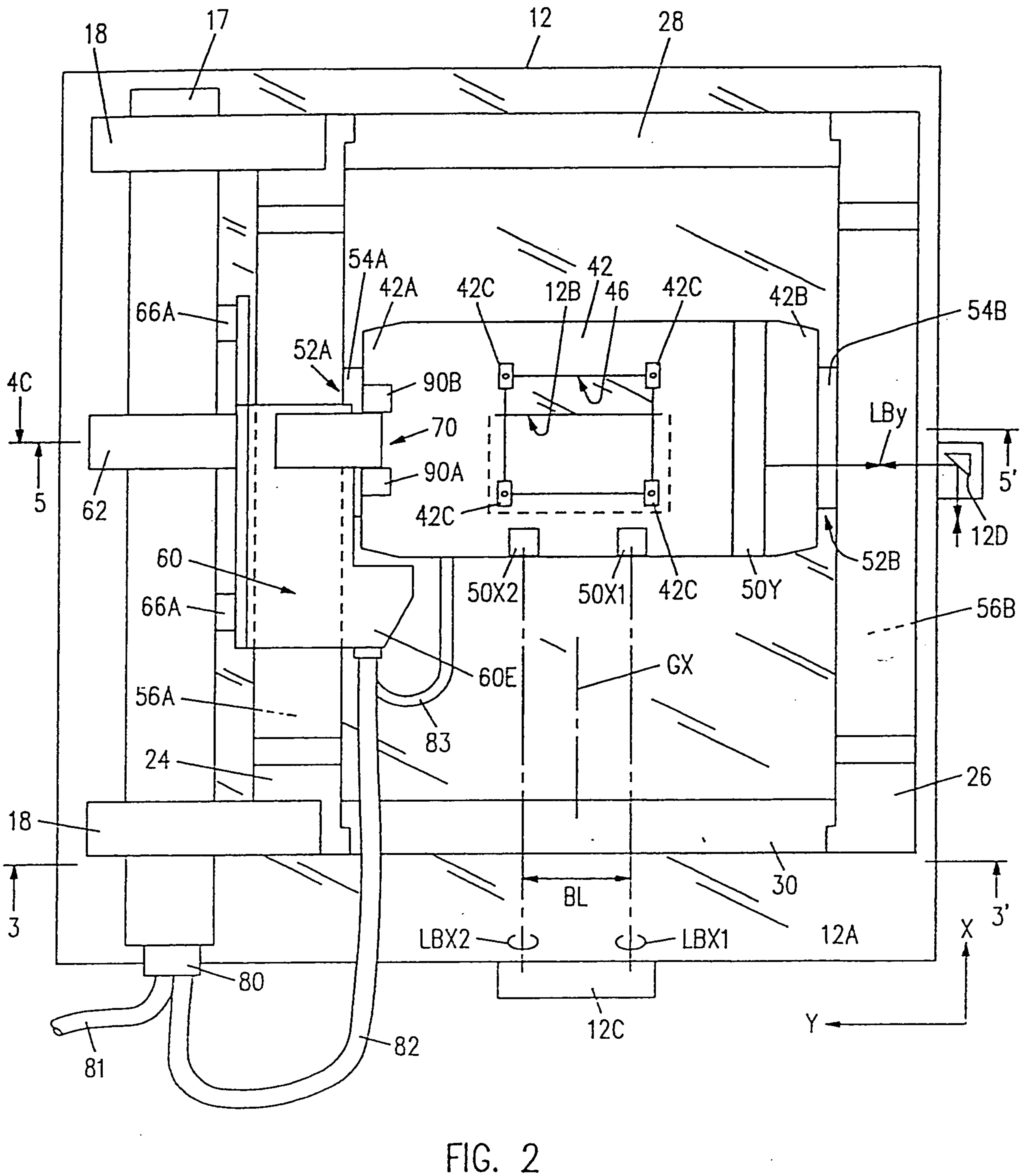

18
17
12
28
54A
42A
42C
42
12B
46
42C
42B
54B
66A
52A
90B
4C
70
LBy
90A
5
62
5'
42C
12D
60
52B
50X2
50X1
42C
50Y
66A
56B
60E
GX
56A
83
24
26
18
30
3
BL
3'
LBX2
LBX1
12A
X
80
Y
12C
81
82

FIG. 2

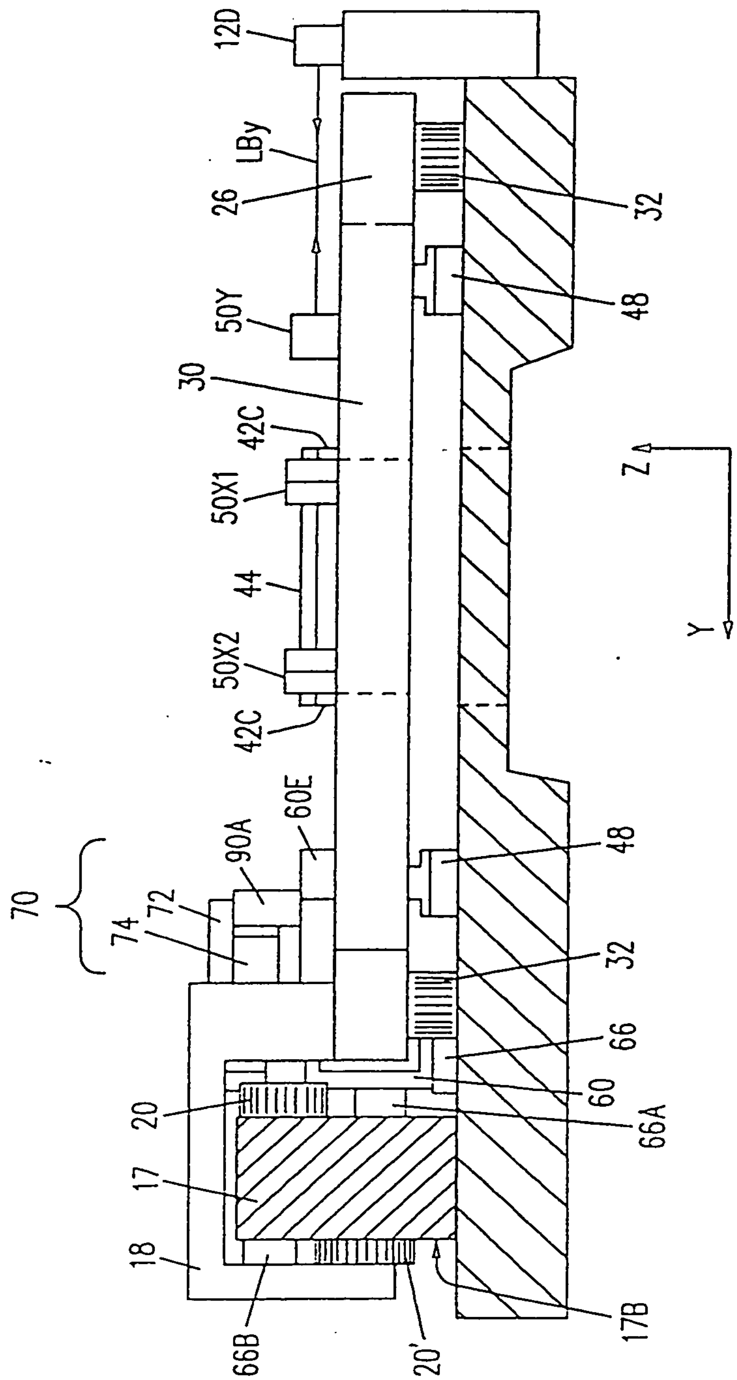

12D
LBy
26
32
50Y
48
30
42C
50X1
44
50X2
42C
60E
90A
70
72
74
48
32
66
60
66A
20
17
18
66B
20'
17B
Z
Y

FIG. 3

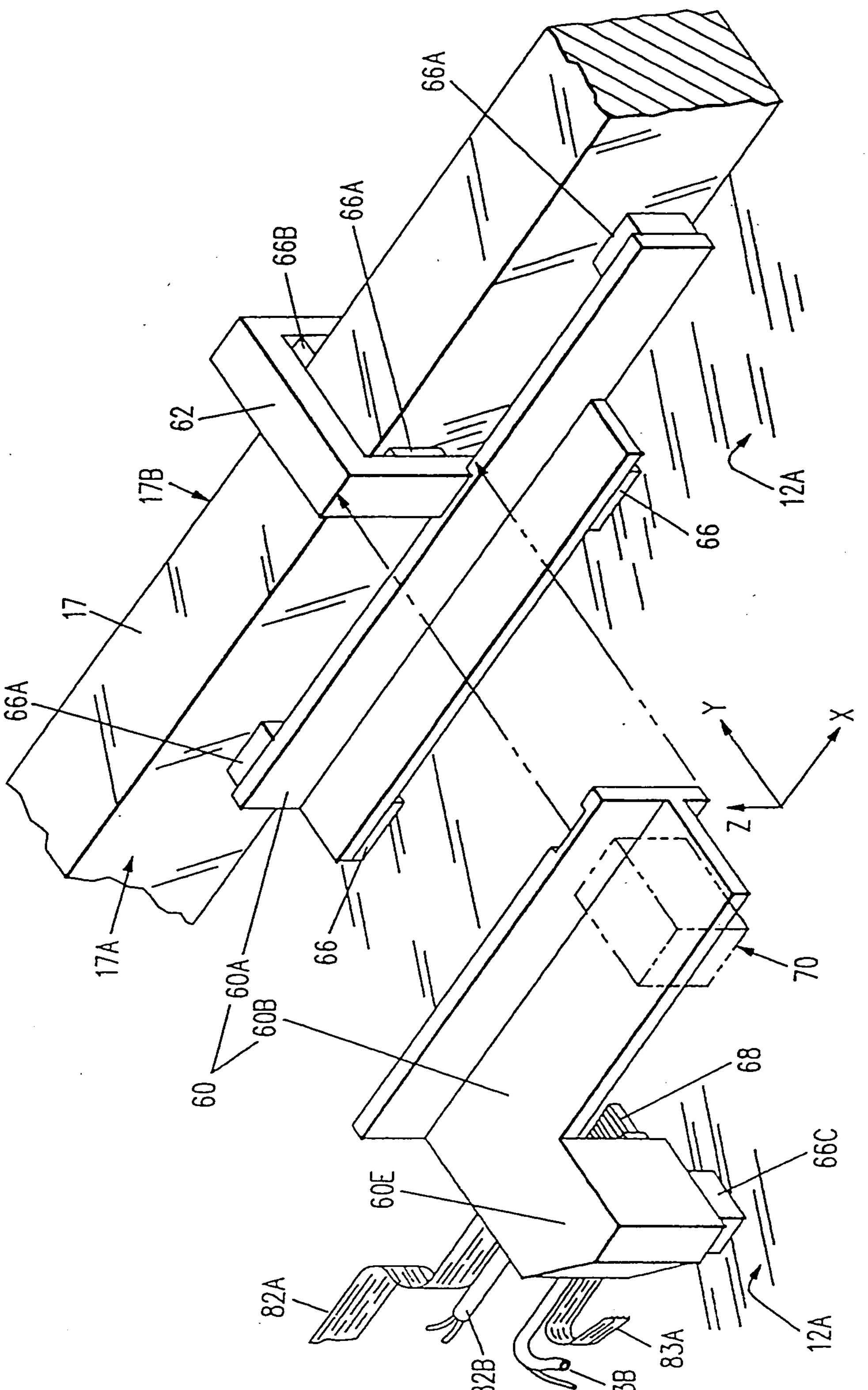
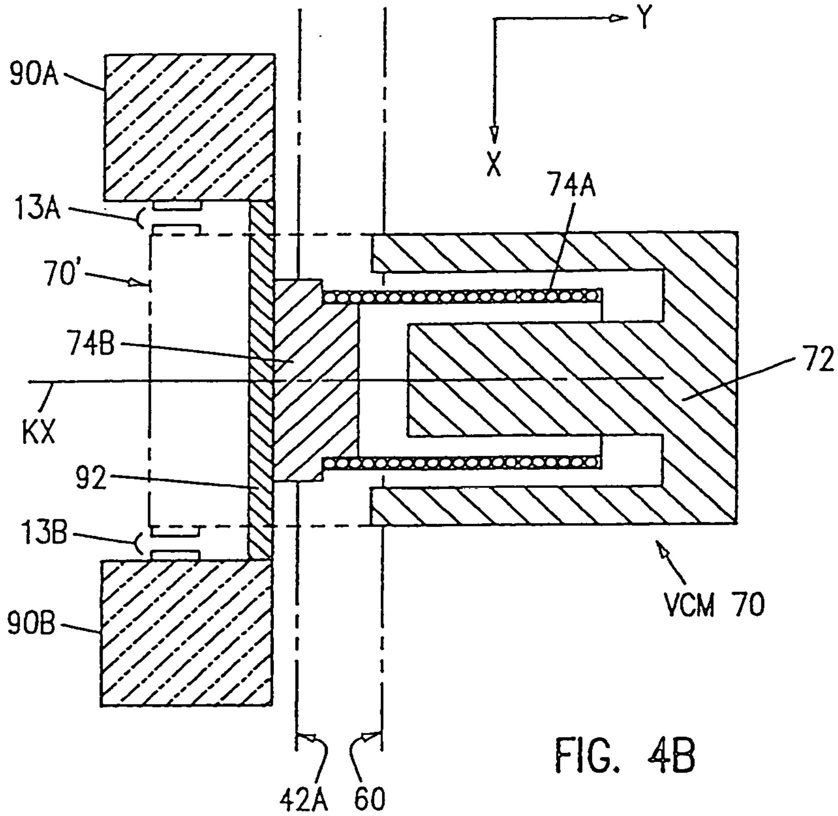
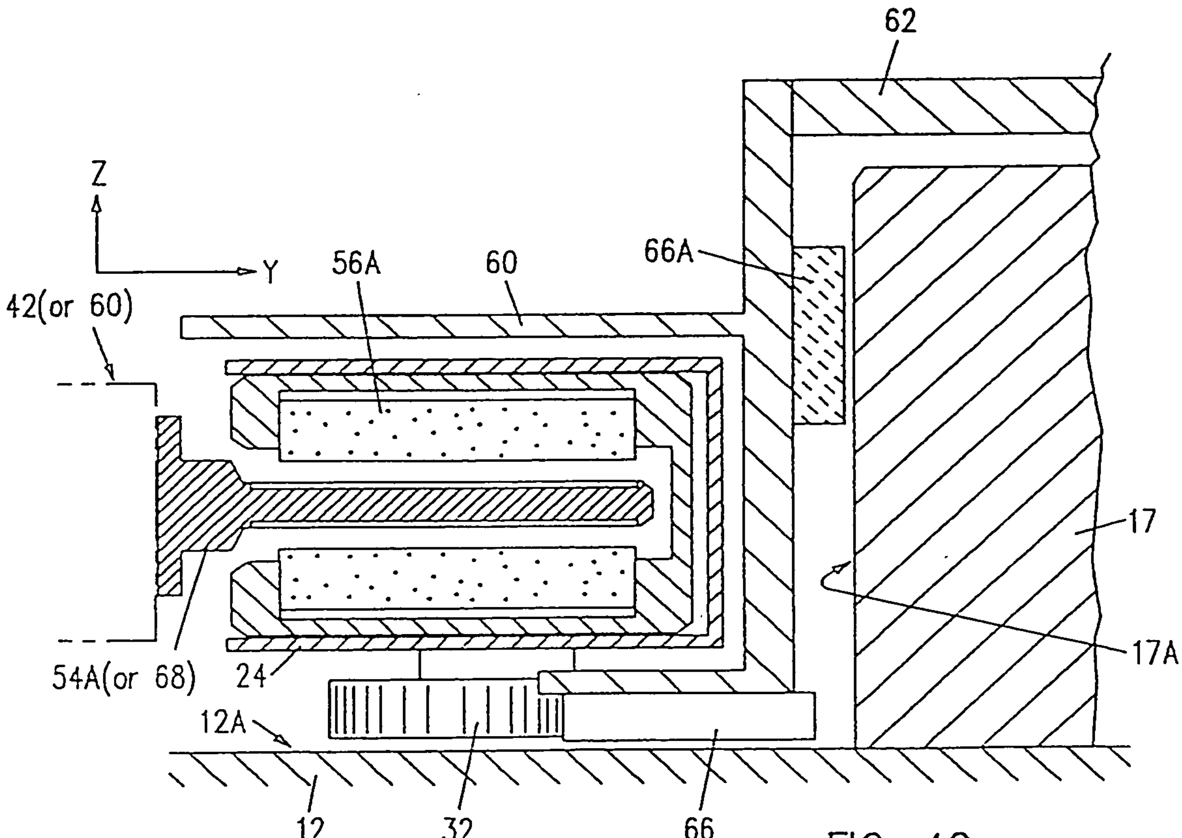

66A
66A
66B
62
17B
17
66A
17A
60A
60B
60
66
66
12A
Y
X
Z
70
68
66C
60E
82A
82B
83B
83A
12A

FIG. 4A



Y
X
90A
13A
70'
74A
74B
72
KX
92
13B
90B
VCM 70
42A
60

FIG. 4B



62
Z
Y
56A
60
66A
42(or 60)
17
17A
54A(or 68)
24
12A
12
32
66

FIG. 4C

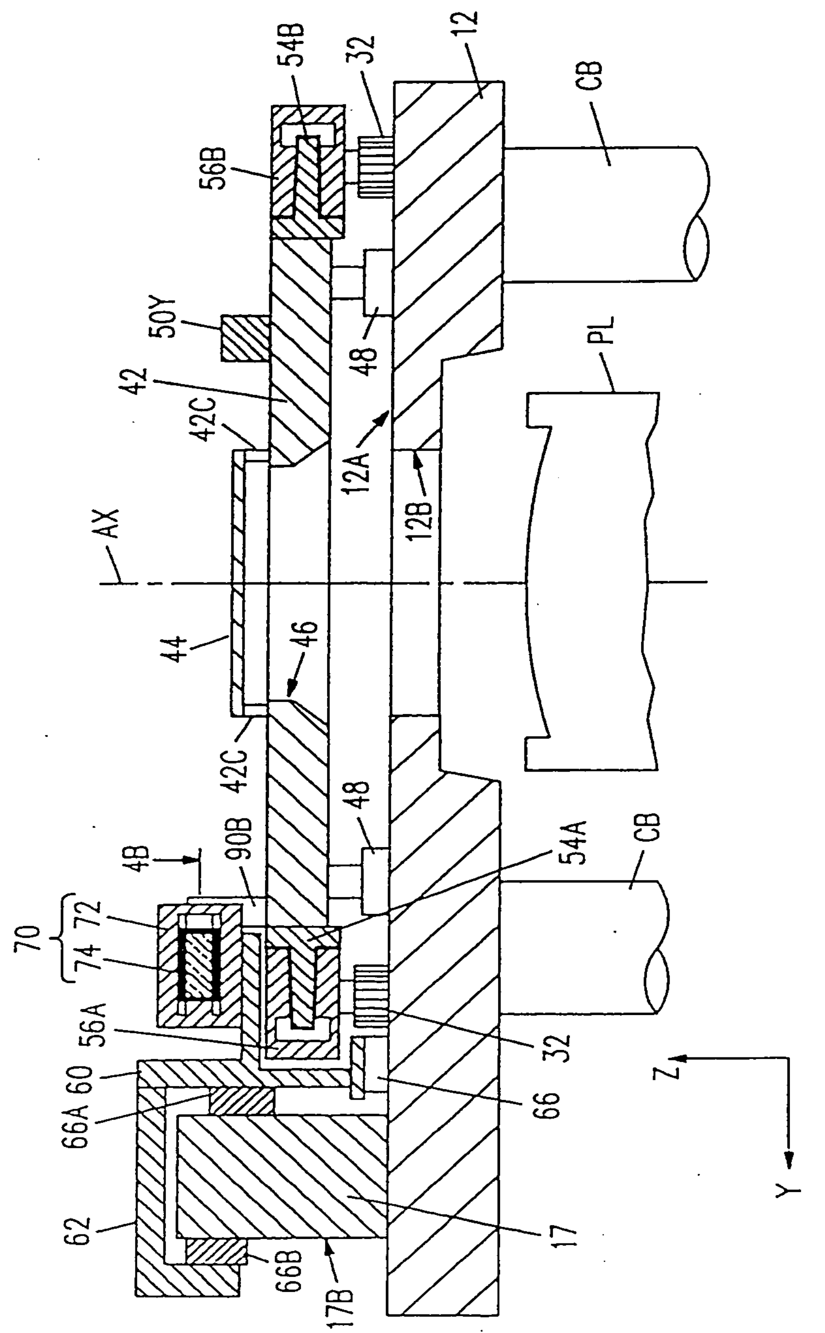

54B
32
12
CB
56B
50Y
48
PL
42
42C
12A
12B
AX
44
46
42C
48
CB
54A
4B
90B
70
72
74
56A
32
60
66A
66
Z
Y
62
17
66B
17B

FIG. 5

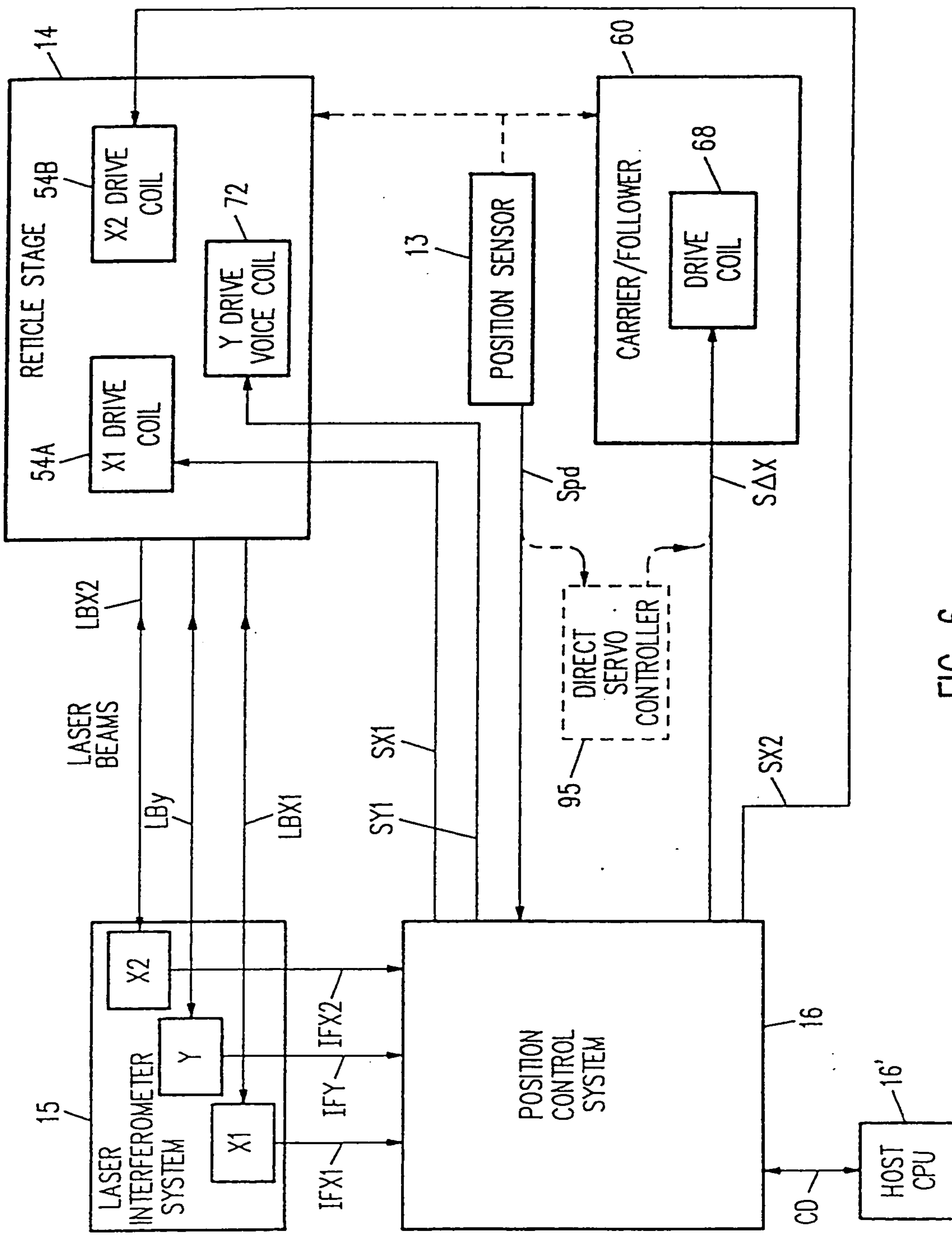

14
RETICLE STAGE
54B
X2 DRIVE COIL
72
Y DRIVE VOICE COIL
54A
X1 DRIVE COIL
13
POSITION SENSOR
60
CARRIER/FOLLOWER
68
DRIVE COIL
Spd
SΔX
95
DIRECT SERVO CONTROLLER
LBX2
LASER BEAMS
LBy
LBX1
SX1
SY1
SX2
15
LASER INTERFEROMETER SYSTEM
X2
Y
X1
IFX2
IFY
IFX1
POSITION CONTROL SYSTEM
16
16'
HOST CPU
CO

FIG. 6

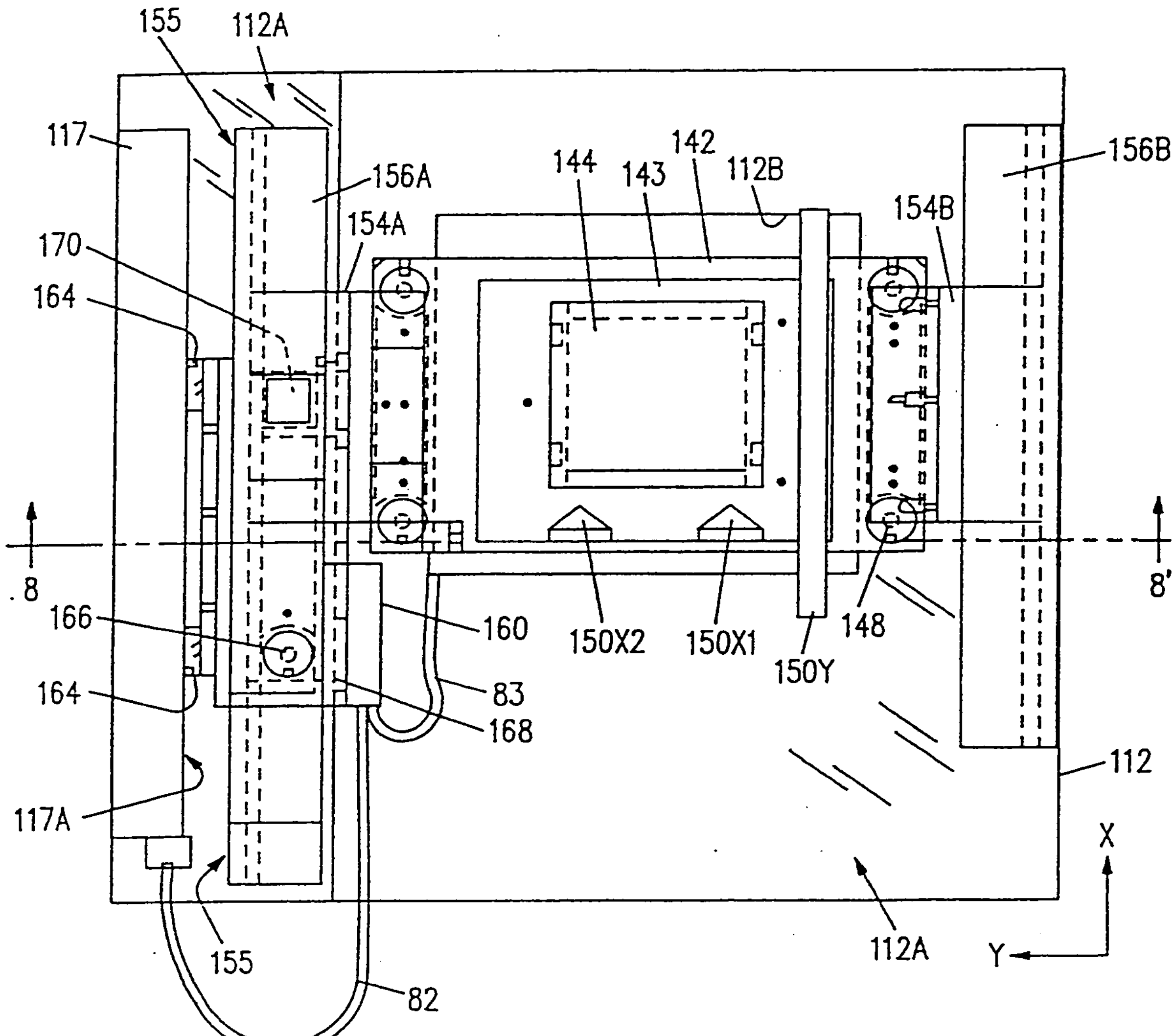

155
112A
117
156A
154A
144
143
142
112B
156B
154B
170
164
8
166
164
117A
155
82
160
83
168
150X2
150X1
150Y
148
8'
112
112A
X
Y

FIG. 7

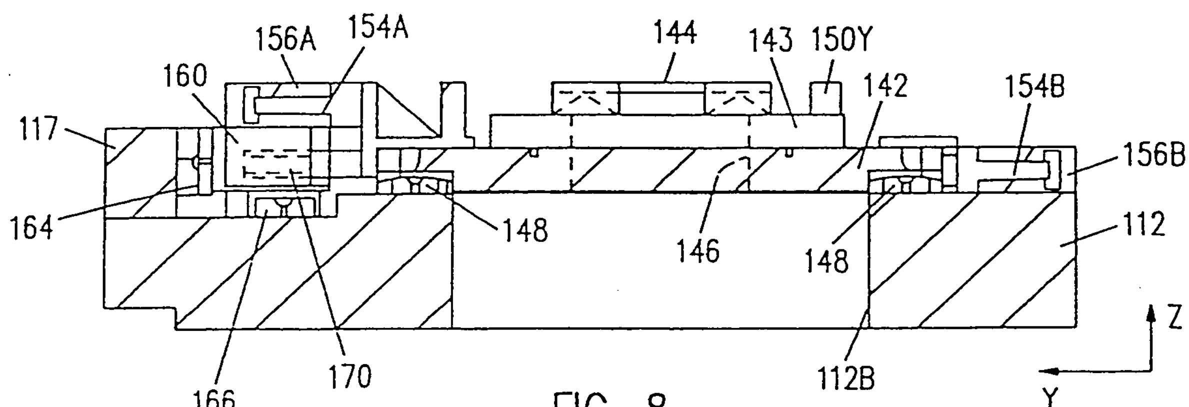

156A
154A
160
117
164
166
170
148
144
143
150Y
142
146
148
112B
154B
156B
112
Z
Y

FIG. 8

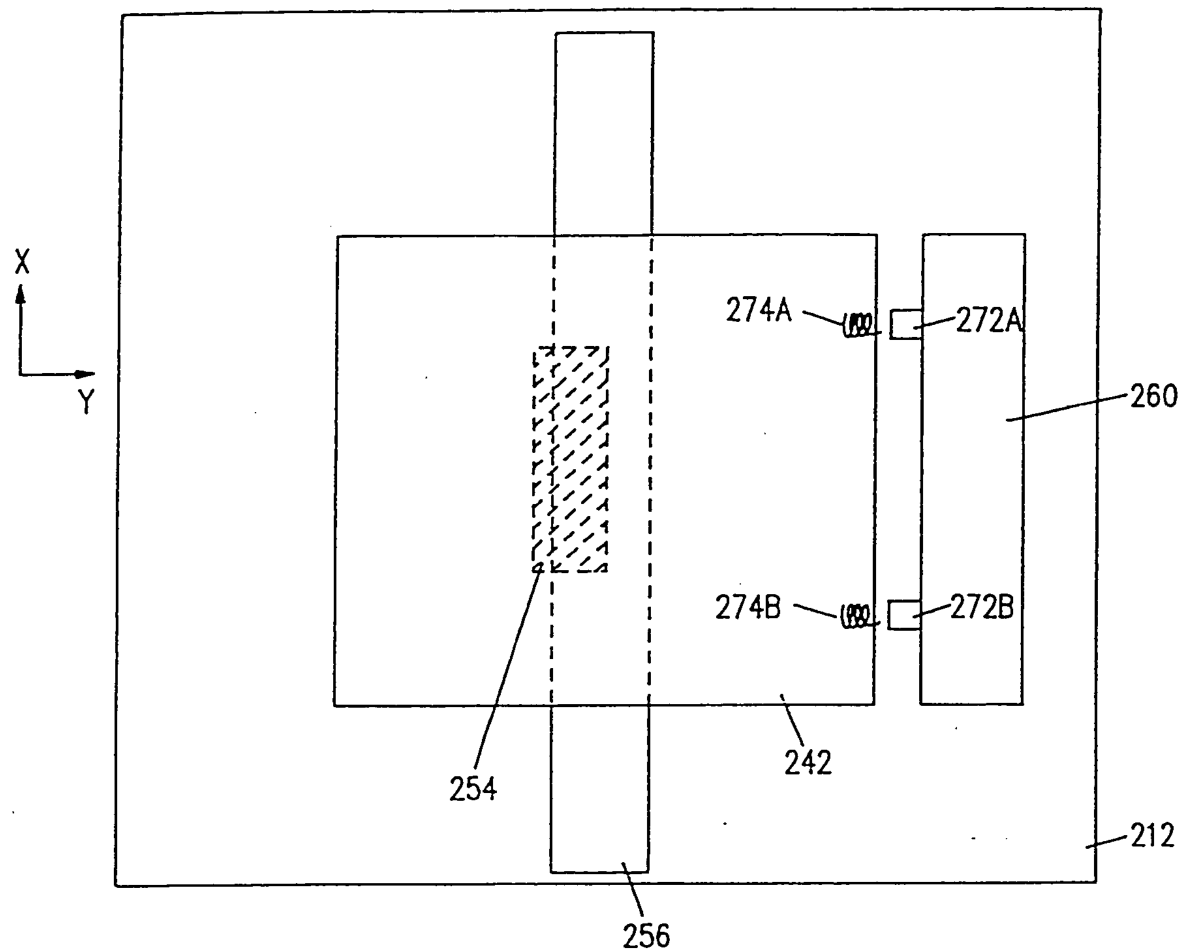


FIG. 9

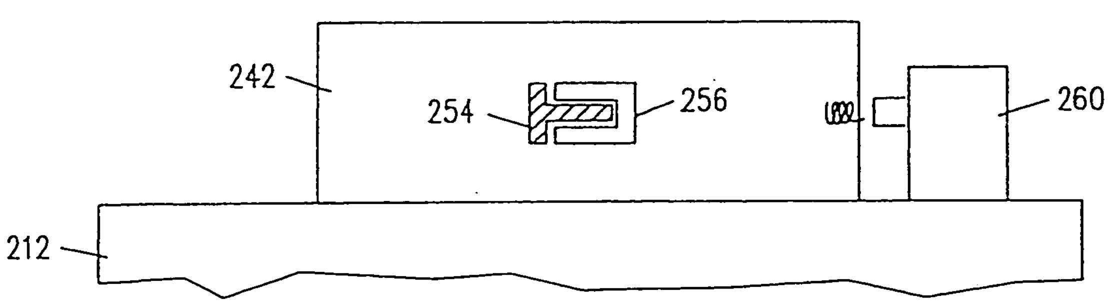


FIG. 10

ELECTROMAGNETIC ALIGNMENT AND SCANNING APPARATUS

The present invention relates to a movable stage apparatus capable of precise movement, and particularly relates to a stage apparatus movable in one linear direction capable of high accuracy positioning and high speed movement, which can be especially favorably utilized in a microlithographic system.

In wafer steppers, the alignment of an exposure field to the reticle being imaged affects the success of the circuit of that field. In a scanning exposure system, the reticle and wafer are moved simultaneously and scanned across one another during the exposure sequence. This invention discloses an apparatus to achieve precise scanning motion for such a system.

To attain high accuracy, the stage should be isolated from mechanical disturbances. This is achieved by employing electromagnetic forces to position and move the stage. It should also have high control bandwidth, which requires that the stage be a light, structure with no moving parts. Furthermore, the stage should be free from excessive heat generation which might cause interferometer interference or mechanical changes that compromises alignment accuracy.

Commutatorless electromagnetic alignment apparatuses such as the ones disclosed in U.S. Pat. Nos. 4,506,204, 4,506,205 and 4,507,597 are not feasible because they

require the manufacture of large magnet and coil assemblies that are not commercially available. The weight of the stage and the heat generated also render these designs inappropriate for high accuracy applications.

An improvement over these commutatorless apparatuses was disclosed in U.S. Pat. No. 4,952,858, which employs a conventional XY mechanically guided sub-stage to provide the large displacement motion in the plane, thereby eliminating the need for large magnet and coil assemblies. The electromagnetic means mounted on the sub-stage isolates the stage from mechanical disturbances. Nevertheless, the combined weight of the sub-stage and stage still results in low control bandwidth and the heat generated by the electromagnetic elements supporting the stage is still substantial.

Even though current apparatus using commutated electromagnetic means is a significant improvement over prior commutatorless ones, the problems of low control bandwidth and interferometer interference persist. In such an apparatus, a sub-stage is moved magnetically in one linear direction and the commutated electromagnetic means mounted on the sub-stage in turn moves the stage in the normal direction. The sub-stage is heavy because it carries the magnet tracks to move the stage. Moreover, heat dissipation on the stage compromises interferometer accuracy.

It is also well known to move a movable member (stage) in one long linear direction (e.g. more than 10 cm) by using two of the linear motors in parallel where coil and magnet are combined. In this case, the stage is guided by some sort of a linear guiding member and driven in one linear direction by a linear motor installed parallel to the guiding member. When driving the stage only to the

extent of extremely small stroke, the guidless structure based on the combination of several electromagnetic actuators, as disclosed in the prior art mentioned before, can be adopted. However, in order to move the guideless stage to a long distance in one linear direction, a specially structured electromagnetic actuator as in the prior arts becomes necessary, causing the size of the apparatus to become larger, and as a result, generating a problem of consuming more electricity.

It is an object of the present invention to make it possible for a guidless stage to move in the direction of a long linear motion using electromagnetic force, and to provide a light weight apparatus in which low inertia and high response are achieved.

Furthermore, it is an object of the present invention to provide a guidless stage apparatus using commercially available regular linear motors as electromagnetic actuators for one linear direction motion.

Furthermore, it is an object of the present invention to provide a guideless stage apparatus capable of active and precise position control for small displacements without any contact in the direction orthogonal to the long linear motion direction.

Furthermore, it is an object of the present invention to provide a completely non-contact stage apparatus by providing a movable member (stage body) to move in one linear direction and the second movable member to move sequentially in the same direction, constantly keeping a certain space in between, and providing the electromagnetic force (action and reaction force) in the direction

orthogonal to the linear direction between this second movable member and the stage body.

Furthermore, it is an object of the present invention to provide a non-contact stage apparatus capable of preventing the positioning and running accuracy from deteriorating by changing tension of various cables and tubes to be connected to the non-contact stage body which moves as it supports an object.

Furthermore, it is an object of the present invention to provide a non-contact apparatus which is short in its height, by arranging the first movable member and the second movable member in parallel which move in the opposite linear direction to one another.

Furthermore, it is an object of the present invention to provide an apparatus which is structured so as not to change the location of the center of the gravity of the entire apparatus even when the non-contact stage body moves in one linear direction.

In order to achieve the above mentioned main purposes, the present invention is constructed in a characteristic manner as follows.

An apparatus capable of high accuracy position and motion control is disclosed. The apparatus utilizes linear commutated motors to move a guideless stage in one long linear direction and small yaw rotation in a plane. A carrier/follower holding a single voice coil motor (VCM) is controlled to approximately follow the stage in the direction of the long linear motion. The VCM provides an electromagnetic force to move the stage for small displacements in the plane in a linear direction perpendicular to the direction of the long linear motion to ensure proper alignment. This follower design eliminates the problem of cable drag for the stage since the cables

connected to the stage follow the stage via the carrier/follower. Cables connecting the carrier/follower to external devices will have certain amount of drag, but the stage is free from such disturbances since the VCM on the carrier/follower acts as a buffer by denying the transmission of mechanical disturbances to the stage.

As a specific feature of the invention the linear commutated motors are located on opposite sides of the stage and are mounted on a driving frame. Each linear commutated motor includes a coil member and a magnetic member one of which is mounted on one of the opposed sides of the stage and the other of which is mounted on the driving frame. Both motors drive in the same direction. By driving the motors slightly different amounts small yaw rotation of the stage is produced.

In accordance with another aspect of the present invention a moving counter-weight is provided to preserve the location of the center of gravity of the stage system during any stage motion by using the conservation of momentum principle. In an embodiment of the present invention the drive frame carrying one member of each of the linear motors is suspended above the base structure, and when the drive assembly applies an action force to the stage to move the stage in one direction over the base structure, the driving frame moves in the opposite direction in response to the reaction force to substantially maintain the center of gravity of the apparatus. This apparatus essentially eliminates any reaction forces between the stage system and the base structure on which the stage system is mounted, thereby facilitating high acceleration while minimizing vibrational effects on the system.

By restricting the stage motion to the three specified degrees of freedom, the apparatus is simple. By using electromagnetic components that are commercially available, the apparatus design is easily adaptable to changes in the size of the stage. This high accuracy positioning apparatus is ideally suited for use as a reticle scanner in a scanning exposure system by providing smooth and precise scanning motion in one linear direction and ensuring accurate alignment by controlling small displacement motion perpendicular to the scanning direction and small yaw rotation in the plane.

Other aspects and features and advantages of the present invention will become more apparent upon a perusal of the following specification taken in conjunction with the accompanying drawings wherein similar characters of reference indicate similar elements in each of the several views, and in which:

Fig. 1 is a schematic perspective view of apparatus in accordance with the present invention.

Fig. 2 is a top plan view of the apparatus shown in Fig. 1.

Fig. 3 is an end elevational view of the structure shown in Fig. 2 taken along line 3-3' in the direction of the arrows.

Fig. 4A is an enlarged perspective, partially exploded, view showing the carrier/follower structure of Fig. 1 and exploded from the positioning guide.

Fig. 4B is an enlarged horizontal sectional view of a portion of the structure shown in Fig. 5 taken along line 4B in the direction of the arrow.

Fig. 4C is an enlarged elevational sectional view of a portion of the structure shown in Fig. 2 taken along line 4C in the direction of the arrow but with the voice coil motor removed.

Fig. 5 is an elevational sectional view of a portion of the structure shown in Fig. 2 taken along line 5-5' in the direction of the arrows.

Fig. 6 is a block diagram schematically illustrating the sensing and control systems for controlling the position of the stage.

Fig. 7 is a plane view, similar to Fig. 2, illustrating the preferred embodiment of the present invention.

Fig. 8 is an elevational sectional view of the structure shown in Fig. 7 taken along line 8-8' in the direction of the arrows.

Figs. 9 and 10 are much simplified schematic views similar to Figs. 7 and 8 and illustrating still another embodiment of the present invention.

While the present invention has applicability generally to electromagnetic alignment systems, the preferred embodiment involves a scanning apparatus for a reticle stage as illustrated in Figs. 1-6.

Referring now to the drawings, the positioning apparatus 10 of the present invention includes a base structure 12 above which a reticle stage 14 is suspended and moved as desired, a reticle stage position tracking laser interferometer system 15, a position sensor 13 and a position control system 16 operating from a CPU 16' (see Fig. 6).

An elongate positioning guide 17 is mounted on the base 12, and support brackets 18 (two brackets in the illustrated embodiment) are movably supported on the guide 17 such as by air bearings 20. The support brackets 18 are connected to a driving assembly 22 in the form of a magnetic track assembly or driving frame for driving the reticle stage 14 in the X direction and small yaw rotation. The driving frame includes a pair of parallel spaced apart magnetic track arms 24 and 26 which are connected together to form an open rectangle by cross arms 28 and 30. In the preferred embodiment the driving frame 22 is movably supported on the base structure 12 such as by air bearings 32 so that the frame is free to move on the base structure in a direction aligned with the longitudinal axis of the guide 17, the principal direction in which the scanning motion of the reticle stage is desired. As used herein "one direction" or a "first direction" applies to movement of the frame 22 or the reticle stage 14 either forward or back in the X direction along a line aligned with the longitudinal axis of the guide 17.

Referring now to Figs. 1 and 5 to explain further in detail, the elongate guiding member 17 in the X direction has front and rear guiding surfaces 17A and 17B which are almost perpendicular to the surface 12A of the base structure 12. The front guiding surface 17A is against the rectangular driving frame 22 and guides the air bearing 20 which is fixed to the inner side of the support bracket 18. A support bracket 18 is mounted on each end of the upper surface of the arm 24 which is parallel to the guiding member 17 of the driving frame 22. Furthermore, each support bracket 18 is formed in a hook shape so as to straddle the guiding member 17 in the Y direction and with the free end against the rear guiding surface 17B of the rear side of the guiding member 17. The air bearing 20' is fixed inside the free end of the support brackets 18 and against the rear guiding surface 17B. Therefore, each of the support brackets 18 is constrained in its displacement in the Y direction by the guiding member 17 and air bearings 20 and 20' and is able to move only in the X direction.

Now, according to this first embodiment of the present invention, the air bearings 32, which are fixed to the bottom surfaces of the four rectangular parts of the driving frame 22, make an air layer leaving a constant gap (1 several μm) between the pad surface and the surface 12A of the base structure 12. The driving frame is buoyed up from the surface 12A and supported perpendicularly (in Z direction) by the air layer. It will be explained in detail later, but in Fig. 1, the carrier/follower 60 shown positioned above the upper part of the elongate arm 24 is positioned laterally in the Y direction by air bearings 66A and 66B supported by a bracket 62 against opposite surfaces 17A and 17B of guiding member 17 and vertically in the Z

direction by air bearings 66 above the surface 12A of the base structure 12. Thus, the carrier/follower 60 is positioned so as not to contact any part of the driving frame 22. Accordingly, the driving frame 22 moves only in one linear X direction, guided above the base surface 12A and laterally by the guiding member 17.

Referring now to both Fig. 1 and Fig. 2, the structure of the reticle stage 14 and the driving frame 22 will be explained. The reticle stage 14 includes a main body 42 on which the reticle 44 is positioned above an opening 46. The reticle body 42 includes a pair of opposed sides 42A and 42B and is positioned or suspended above the base structure 12 such as by air bearings 48. A plurality of interferometer mirrors 50 are provided on the main body 42 of the reticle stage 14 for operation with the laser interferometer position sensing system 15 (see Fig. 6) for determining the exact position of the reticle stage which is fed to the position control system 16 in order to direct the appropriate drive signals for moving the reticle stage 14 as desired.

Primary movement of the reticle stage 14 is accomplished with first electromagnetic drive assembly or means in the form of separate drive assemblies 52A and 52B on each of the opposed sides 42A and 42B, respectively The drive assemblies 52A and 52B include drive coils 54A and 54B fixedly mounted on the reticle stage 14 at the sides 42A and 42B, respectively, for cooperating with magnet tracks 56A and 56B on the magnet track arms 24 and 26, respectively, of the drive frame 22. While in the preferred embodiment of the invention the magnet coils are mounted on the reticle stage and the magnets are mounted on the drive frame 22, the positions of these elements of the electromagnetic drive assembly 52 could be reversed.

Here, the structure of the reticle stage 14 will be explained further in detail. As shown in Fig. 1, the stage body 42 is installed so that it is free to move in the Y direction in the rectangular space inside the driving frame 22. The air bearing 48 fixed under each of the four corners of the stage body 42 makes an extremely small air gap between the pad surface and the base surface 12A, and buoys up and supports the entire stage 14 from the surface 12A. These air bearings 48 should preferably be pre-loaded types with a recess for vacuum attraction to the surface 12A.

As shown in Fig. 2, a rectangle opening 46 in the center of the stage body 42 is provided so that the projected image of the pattern formed on the reticle 44 can go through. In order for the projected image via the rectangle opening 46 to pass through the projection optical system PL (See Fig. 5) which is installed below the rectangle opening, there is another opening 12B provided at the center part of the base structure 12. The reticle 44 is loaded on the top surface of the stage body by clamping members 42C which are protrusively placed at four points around the rectangle opening 46, and clamped by the vacuum pressure.

Now, the interferometer mirror 50Y, which is fixed near the side 42B of the stage body 42 near the arm 26, has a vertical elongate reflecting surface in the X direction which length is somehwat longer than the movable stroke of the stage 14 in the X direction, and the laser beam LBY from the Y-axis interferometer is incident perpendicularly on the reflecting surface. In Fig. 2, the laser beam LBY is bent at a right angle by the mirror 12D which is fixed on the side of the base structure 12.

Referring now to Fig. 3 as a partial cross-sectional drawing of the 3-3' view in Fig. 2, the laser beam LBY which is incident on the reflecting surface of the interferometer mirror 50Y is placed so as to be on the same plane as the bottom surface (the surface where the pattern is formed) of the reticle 44 which is mounted on the clamping member 42C. Furthermore, in Fig. 3, the air bearing 20 on the end side of the support brackets 18 against the guiding surface 17B of the guiding member 17 is also shown.

Referring once again to Figs. 1 and 2, the laser beam LBX1 from the X1-axis interferometer is incident and reflected on the interferometer mirror 50X1, and the laser beam LBX2 from the X2-axis interferometer is incident and reflected on the interferometer mirror 50X2. These two mirrors 50X1 and 50X2 are structured as corner tube type mirrors, and even when the stage 14 is in yaw rotation, they always maintain the incident axis and reflecting axis of the laser beams parallel within the XY plane. Furthermore, the block 12C in Fig. 2 is an optical block such as a prism to orient the laser beams LBX1 and LBX2 to each of the mirrors 50X1 and 50X2, and is fixed to a part of the base structure 12. The corresponding block for the LBy laser beam is not shown.

In Fig. 2, the distance BL in the Y direction between each of the center lines of the two laser beams LBX1 and LBX2 is the length of the base line used to calculate the amount of yaw rotation. Accordingly, the value of the difference between the measured value $\Delta X1$ in the X direction of the X1-axis interferometer and the measured value $\Delta X2$ in the X direction of the X2-axis interferometer divided by the base line length BL is the approximate amount of yaw rotation in an extremely small range. Also,

half the value of the sum of the $\Delta X1$ and $\Delta X2$ represents the X coordinate position of the entire stage 14. These calculations are done on the high speed digital processor in the position control system 16 shown in Fig. 6.

Furthermore, the center lines of each of the laser beams LBX1 and LBX2 are set on the same surface where the pattern is formed on the reticle 44. The extension of the line GX, which is shown in Fig. 2 and divides in half the space between each of the center lines of laser beams LBX1 and LBX2, and the extension of the laser beam LBY intersect within the same surface where the pattern is formed. And furthermore, the optical axis AX (See Figs. 1 and 5) also crosses at this intersection as shown in Fig. 1. In Fig. 1, a slit shape illumination field ILS which includes the optical axis AX is shown over the reticle 44, and the pattern image of the reticle 44 is scanned and exposed onto the photo-sensitive substrate via the projection optical system PL.

Furthermore, there are two rectangular blocks 90A and 90B fixed on the side 42A of the stage body 42 in Figs. 1 and 2. These blocks 90A and 90B are to receive the driving force in the Y direction from the second electro-magnetic actuator 70 which is mounted on the carrier/follower 60. Details will be explained later.

The driving coils 54A and 54B which are fixed on the both sides of the stage body 42 are formed flat parallel to the XY plane, and pass through the magnetic flux space in the slot which extends in the X direction of the magnetic track 56A and 56B without any contact. The assembly of the driving coil 54 and the magnetic track 56 used in the present embodiment is a commercially easily accessible linear motor for general purposes, and it could be either with or without a commutator.

Here, considering the actual design, the moving stroke of the reticle stage 14 is mostly determined by the size of the reticle 44 (the amount of movement required at the time of scanningfor exposure and the amount of movement needed at the time of removal of the reticle from the illumination optical system to change the reticle). In the case of the present embodiment, when a 6-inch reticle is used, the moving stroke is about 30 cm.

As mentioned before, the driving frame 22 and the stage 14 are independently buoyed up and supported on the base surface 12A, and at the same time, magnetic action and reaction force is applied to one another in the X direction only by the linear motor 52. Because of that, the law of the conservation of momentum is seen between the driving frame 22 and the stage 14.

Now, suppose the weight of the entire reticle stage 14 is about one fifth of the entire weight of the frame 22 which includes the support brackets 18, then the forward movement of 30 cm of the stage 14 in the X direction makes the driving frame 22 move by 6 cm backwards in the X direction. This means that the location of the center of the gravity of the apparatus on the base structure 12 is essentially fixed in the X direction. In the Y direction, there is no movement of any heavy object. Therefore, the change in the location of the center of the gravity in the Y direction is also relatively fixed.

The stage 14 can be moved in the X direction as described above, but the moving coils (54A, 54B) and the stators (56A, 56B) of the linear motors 52 will interfere with each other (collide) in the Y direction without an X direction actuator. Therefore, the carrier/follower 60 and the second electromagnetic actuator 70, which are the

characteristic components of the present invention, are provided to control the stage 14 in the Y direction.

Referring now to Figs. 1, 2, 3, and 5, the structures of them will be explained here.

As shown in Fig. 1, the carrier/follower 60 is movably installed in the Y direction via the hook like support bracket 62 which straddles over the guiding member 17. Furthermore as evident from Fig. 2, the carrier/follower 60 is placed above the arm 24, so as to maintain a certain space between the stage 14 (the body 42) and to the arm 24, respectively. One end 60E of the carrier/follower 60, is substantially protruding inward (toward the stage body 42) over the arm 24. Inside this end part 60E is fixed a driving coil 68 (same shape as the coil 54) which enters a slot space of the magnetic track 56A.

Furthermore, the bracket 62 supported air bearing 66A (See Figs. 2, 3, 4A and 5) against the guiding surface 17A of the guiding member 17 is fixed in the space between the guiding member 17 of the carrier/follower 60 and the arm 24. The air bearing 66 to buoy up and support the carrier/follower 60 on the base surface 12A is also shown in Fig. 3.

The air bearing 66B against the guiding surface 17B of the guiding member 17 is also fixed to the free end of support bracket 62 on the other side of the hook from air bearing 66A with guiding member 17 therebetween.

Now, as evident from Fig. 5, the carrier/follower 60 is arranged so as to keep certain spaces with respect to both the magnetic track 56A and the stage body 42 in the Y and Z directions, respectively. Shown in Fig. 5 are the projection optical system PL and column rod CB to support the base structure 12 above the projection optical system

PL. Such an arrangement is typical for a projection aligner, and unnecessary shift of the center of the gravity of the structures above the base structure 12 would cause a lateral shift (mechanical distortion) between the column rod CB and the projection optical system PL, and thus result in a deflection of the image on the photosensitive substrate at the time of exposure. Hence, the merit of the device as in the present embodiment where the motion of the stage 14 does not shift the center of the gravity above the base structure 12 is substantial.

Furthermore referring now to Fig. 4A, the structure of the carrier/follower 60 will be explained. In Fig. 4A, the carrier/follower 60 is disassembled into two parts, 60A and 60B, for the sake of facilitating one's understanding. As evident from Fig. 4A, the driving coil 68 to move the carrier/follower 60 itself in the X direction is fixed at the lower part of the end 60E of the carrier/follower 60. Furthermore, the air bearing 66C is placed against the base structure 12A on the bottom surface of the end 60E and helps to buoy up the carrier/follower 60.

Hence the carrier/follower 60 is supported in the Z direction with the following three points, the two air bearings 66 and one air bearing 66C, and is constrained in the Y direction for movement in the X direction by air bearings 66A and 66B. What is important in this structure is that the second electromagnetic actuator 70 is arranged back to back with the support bracket 62 so that when the actuator generates the driving force in the Y direction, reaction forces in the Y direction between the stage 14 and the carrier/follower 70 actively act upon the air bearings 66A and 66B which are fixed inside the support bracket 62. In other words, arranging the actuator 70 and the air bearings 66A, 66B on the line parallel to the y-axis in the

XY plane helps prevent generating unwanted stress, which might deform the carrier/follower 60 mechanically when the actuator 70' is in operation. Conversely, it means that it is possible to reduce the weight of the carrier/follower 60.

As evident from Figs. 2, 4A and 4C described above, the magnetic track 56A in the arm 24 of the driving frame 22 provides magnetic flux for the driving coil 54A on the stage body 42 side, and concurrently provides magnetic flux for the driving coil 68 for the carrier/follower 60. As for the air bearings 66A, 66B and 66C, a vacuum pre-loaded type is preferable, since the carrier/follower 60 is light. Besides the vacuum pre-loaded type, a magnetic pre-loaded type is also acceptable.

Next with reference to Figs. 3, 4B and 5, the second actuator mounted on the carrier/follower 60 will be explained. A second electromagnetic drive assembly in the form of a voice coil motor 70 is made up of a voice coil 74 attached to the main body 42 of the reticle stage 14 and a magnet 72 attached to the carrier/follower 60 to move the stage 14 for small displacements in the Y direction in the plane of the travel of the stage 14 orthogonal to the X direction long linear motion produced by the driving assembly 22. The positions of the coil 74 and magnet 72 could be reversed. A schematic structure of the voice coil motor (VCM) 70 is as shown in Figs. 3 and 5, and the detailed structure is shown in Fig. 4B. Shown in Fig. 4B is a cross-sectional view of the VCM 70 sectioned at the horizontal plane shown with an arrow 4B in Fig. 5. In Fig. 4B, the magnets 72 of the VCM 70 are fixed onto the carrier/follower 60 side. And the coil of the VCM 70 comprises the coil body 74A and its supporting part 74B, and the supporting part 74B is fixed to a connecting plate

92 (a plate vertical to the XY plane) which is rigidly laid across the two rectangular blocks 90A and 90B. A center line KX of the VCM 70 shows the direction of the driving force of the coil 74, and when an electric current flows through the coil body 74A, the coil 74 displaces into either positive or negative movement in the Y direction in accordance with the direction of the current, and generates a force correspondent to the amount of the current. Normally, in a commonly used VCM, a ring-like damper or bellows are provided between the coil and magnet so as to keep the gap between the coil and magnet, but according to the present embodiment, that gap is kept by a follow-up motion of the carrier/follower 60, and therefore, such supporting elements as a damper or bellows are not necessary.

In the present embodiment, capacitance gap sensors 13A and 13B are provided as a positioning sensor 13 (see Fig. 6) as shown in Fig. 4B. In Fig. 4B, electrodes for capacitance sensors are placed so as to detect the change in the gap in the X direction between the side surface of the rectangular blocks 90A and 90B facing with each other in the X direction and the side surface of a case 70' of the VCM 70. Such a positioning sensor 13 can be placed anywhere as far as it can detect the gap change in the Y direction between the carrier/follower 60 and the stage 14 (or the body 42). Furthermore, the type of the sensor can be any of a non-contact type such as photoelectric, inductive, ultrasonic, or air-micro system.

The case 70' in Fig. 4B is formed with the carrier/follower 60 in one, and placed (spatially) so as not to contact any member on the reticle stage 14 side. As for the gap between the case 70' and the rectangular blocks 90A and 90B in the X direction (scanning direction), when

the gap on the sensor 13A side becomes wider, the gap on the sensor 13 B side becomes smaller. Therefore, if the difference between the measured gap value by the sensor 13A and the measured gap value by the sensor 13B is obtained by either digital operation or analog operation, and a direct servo (feedback) control system which controls the driving current of the driving coil 68 for the carrier/follower 60 is designed using a servo driving circuit which makes the gap difference zero, then the carrier/follower 60 will automatically perform a follow-up movement in the X direction always keeping a certain space to the stage body 42. Or, it is also possible to design an indirect servo control system which controls an electric current flow to the driving coil 68, with the operation of position control system 16 in Fig. 6 using the measured gap value obtained only from one of the sensors and the X coordinate position of the stage 14 measured from the X axis interferometer, without using the two gap sensors 13A and 13B differentially.

In the VCM 70 as described in Fig. 4B, the gap between the coil body 74A and the magnet 72 in the X direction (non-energizing direction) is in actuality about 2 - 3 mm. Therefore, a follow-up accuracy of the carrier/follower 60 with respect to the stage body 42 would be acceptable at around ±.5 - 1 mm. This accuracy depends on how much of the yaw rotation of the stage body is allowed, and also depends on the length of the line in the KX direction (energizing direction) of the coil body 74A of the VCM 70. Furthermore, the degree of the accuracy for this can be substantially lower than the precise positioning accuracy for the stage body 42 using an interferometer (e.g., ±0.03 μm supposing the resolution of the interferometer is 0.01 μm.) This means that the servo

system for a follower can be designed fairly simply, and the amount of cost to install the follower control system would be small. Furthermore, the line KX in Fig. 4B is set so as to go through the center of the gravity of the entire stage 14 on the XY plane, and each of centers of the pair of the air bearing 66A and 66B provided inside the support brackets 62 shown in Fig. 4 is also positioned on the line KX in the XY plane.

Shown in Fig. 4C is a cross-sectional drawing of the part which includes the guiding member 17, the carrier/follower 60, and the magnetic track 56A sectioned from the direction of the arrow 4C in Fig. 2. The arm 24 storing the magnetic track 56A is buoyed up and supported on the base surface 12A by the air bearing 32, and the carrier/follower 60 is buoyed up and supported on the base surface 12A by the air bearing 66. At this time, the height of the air bearing 48 at the bottom surface of the stage body 42 (see Figs. 3 or 5) and the height of the air bearing 32 are determined so as to place the driving coil 54A on the stage body 42 side keeping a 2 - 3 mm gap in Z direction in the slot space of the magnetic track 56A.

Each of the spaces between the carrier/follower 60 and the arm 24 in the Z and Y directions hardly changes because they are both guided by the common guiding member 17 and the base surface 12A. Furthermore, even if there is a difference in the height in the Z direction between the part on the base surface 12A where the air bearing 32 at the bottom surface of the driving frame 22 (arm 24) is guided and the part on the base surface 12A where the air bearing 48 at the bottom surface of the stage body is guided, as long as the difference is precisely constant within the moving stroke, the gap in the Z direction

between the magnetic track 56A and the driving coil 54A is also preserved constant.

Furthermore, since the driving coil 68 for the carrier/follower 60 is originally fixed to the carrier/follower 60, it is arranged, maintaining a certain gap of 2 - 3 mm above and below in the slot space of the magnetic track 56A. And the driving coil 68 hardly shifts in the Y direction with respect to the magnetic track 56A.

Cables 82 (see Fig. 2) are provided for directing the signals to the drive coils 54A and 54B on stage 14, the voice coil motor coil 74 and the carrier/follower drive coil 68, and these cables 82 are mounted on the carrier/follower 60 and guide 17 thereby eliminating drag on the reticle stage 14. The voice coil motor 70 acts as a buffer by denying transmission of external mechanical disturbances to the stage 14.

Therefore, referring now to Figs. 2 and 4A, the cable issues will be described further in detail. As shown in Fig. 2, a connector 80 which connects wires of the electric system and tubes of the air pressure and the vacuum system (hereinafter called "cables") is mounted on the base structure 12 on one end of the guiding member 17. The connector 80 connects a cable 81 from the external control system (including the control system of air pressure and vacuum system besides the electric system control system shown in Fig. 6) to a flexible cable 82. The cable 82 is further connected to the end part 60E of the carrier/follower 60, and electric system wires and the air pressure and the vacuum system tubes necessary for the stage body 42 are distributed as the cable 83.

As mentioned before, the VCM 70 works to cancel a cable's drag or an influence by tension, but sometimes its influence appears as moment in unexpected direction between

the carrier/follower 60 and the stage body 42. In other words, the tension of the cable 82 gives the carrier/follower 60 a force to rotate the guiding surface of the guiding member 17 or the base surface 12A, and the tension of the cable 83 gives a force to the carrier/follower 60 and the stage body to rotate relatively.

One of these moments, the constituent which shifts the carrier/follower 60, is not problematic, but the one which shifts the stage body in X, Y, or θ direction (yaw rotation direction) could affect the alignment or overlay accuracy. As for in X and θ directions, shifts can be corrected by a consecutive drive by the two linear motors (54A,56A,54B,56B), and as for in the Y direction, the shift can be corrected by the VCM 70. In the present embodiment, since the weight of the entire stage 14 can be reduced substantially, the response of the motion of the stage 14 by VCM 70 in the Y direction and the response by the linear motor in X and θ directions will be extremely high in cooperation with the completely non-contact guidless structure. Furthermore, even when a micro vibration (micron order) is generated in the carrier/follower 60 and it is transferred to the stage 14 via the cable 83, the vibration (from several Hz to tens of Hz) can be sufficiently canceled by the above mentioned high response.

Now, Fig. 4A shows how each of the cables is distributed at the carrier/follower 60. Each of the driving signals to the driving coil 54A, 54B for the stage body 42 and the driving coil 74 of the VCM 70 and the detection signal from the position sensor 13 (the gap sensors 13A, 13B) go through the electric system wire 82A from the connector 80. The pressure gas and the vacuum to each of the air bearings 48 and 66 go through the pneumatic

system tube 82B from the connector 80. On the other hand, the driving signal to the driving coil 54A and 54B goes through the electric system wire 83A which is connected to the stage body 42, and the pressurized gas for the air bearing 48 and the vacuum for the clamping member 42C go through the pneumatic system hoses 83B.

Furthermore, it is preferable to have a separate line for the pneumatic system for the air bearings 20, 20' and 32 of the driving frame 22, independent of the one shown in Fig. 2. Also, as shown in Fig. 4A, in case the tension or vibration of the cable 83 cannot be prevented, it is advisable to arrange the cable 83 so as to limit the moment by the tension or vibration the stage body 42 receives only to Y direction as much as possible. In that case, the moment can be canceled only by the VCM 70 with the highest response.

Referring now to Figs. 1, 2 and 6, the positioning of the reticle stage 14 is accomplished first knowing its existing position utilizing the laser interferometer system 15. Drive signals are sent to the reticle stage drive coils 54A and 54B for driving the stage 14 in the X direction. A difference in the resulting drive to the opposite sides 42A and 42B of the reticle stage 14 will produce small yaw rotation of the reticle stage 14. An appropriate drive signal to the voice coil 72 of voice coil motor 70 produces small displacements of the reticle stage 14 in the Y direction. As the position of the reticle stage 14 changes, a drive signal is sent to the carrier/follower coil 68 causing the carrier/follower 60 to follow the reticle stage 14. Resulting reaction forces to the applied drive forces will move the magnetic track assembly or drive frame 22 in a direction opposite to the movement of the reticle stage 14 to substantially maintain

the center of gravity of the apparatus. It will be appreciated that the counter-weight or reaction movement of the magnetic track assembly 22 need not be included in the apparatus in which case the magnetic track assembly 22 could be fixedly mounted on the base 12.

As described above, in order to control the stage system according to the present embodiment, a control system as shown in Fig. 6 is installed. This control system in Fig. 6 will be further explained in detail here. X1 driving coil and X2 driving coil composed as the driving coils 54A and 54B of two linear motors respectively, and Y driving coil composed as the driving coil 72 of the VCM 70 are placedin the reticle stage 14, and the driving coil 68 is placed in the carrier/follower 60. Each of these driving coils is driven in response to the driving signals SX1, SX2, SY1, and SΔX, respectively, from the position control system 16. The laser interferometer system which measures the coordinates position of the stage 14 comprises the Y axis interferometer which sends/receives the beam LBY, the X1 axis interferometer which sends/receives the beam LBX1, and the X2 axis interferometer which sends/receives the beam LBX2, and they send position information for each of the directions of the axes, IFY, IFX1, IFX2 to the position control system 16. The position control system 16 sends two driving signals SXI and SX2 to the driving coils 54A and 54B so that the difference between the position information IFX1 and IFX2 in the X direction will become a preset value, or in other words, the yaw rotation of the reticle stage 14 is maintained at the specified amount. Thus, the yaw rotation (in θ direction) positioning by the beams LBX1 and LBX2, X1 axis and X2 axis interferometers, the position control system 16, and the driving signals SX1 and SX2 is constantly being

conducted, once the reticle 44 is aligned on the stage body 42, needless to mention the time of the exposure.

Furthermore, the control system 16, which obtained the current coordinates position of the stage 14 in the X direction from the average of the sum of position information IFX1 and IFX2 in the X direction, sends the driving signals SX1, SX2 to the driving coils 54A and 54B, respectively, based on the various commands from the Host CPU 16' and the information CD for the parameters. Especially when scanning exposure is in motion, it is necessary to move the stage 14 straight in the X direction while correcting the yaw rotation, and the control system 16 controls the two driving coils 54A and 54B to give the same or slightly different forces as needed.

Furthermore, the position information IFY from the Y axis interferometer is also sent to the control system 16, and the control system 16 sends an optimum driving signal SΔX to the driving coil 68 of the carrier/follower 60. At that time, the control system 16 receives the detection signal S_{pd} from the position sensor 13 which measures the space between the reticle stage 14 and the carrier/follower 60 in the X direction, and sends a necessary signal SΔX to make the signal S_{pd} into the preset value As mentioned before, the follow-up accuracy for the carrier/follower 60 is not so strict that the detection signal S_{pd} of the control system 16 does not have to be evaluated strictly either. For example, when controlling the motion by reading the position information IFY, IFX1, IFX2 every 1msecond from each of the interferometers, the high speed processor in the control system 16 samples the current of the detection signal S_{pd} each time, determines whether the value is large or small compared to the reference value (acknowledge the direction), and if the deviation surpasses

a certain point, the signal $S\Delta X$ in proportion to the deviation can be sent to the driving coil 68. Furthermore as mentioned before, it is also acceptable to install a control system 95 which directly servo controls the driving coil 68, and directly controls the follow-up motion of the carrier/follower 60 without going through the position control system 16.

Since the moving stage system as shown has no attachment to constrain it in the X direction, small influences may cause the system to drift toward the positive or negative X direction. This would cause certain parts to collide after this imbalance became excessive. The influences include cable forces, imprecise leveling of the base reference surface 12A or friction between components. One simple method is to use weak bumpers (not shown) to prevent excessive travel of the drive assembly 22. Another simple method is to turn off the air to one or more of the air bearings (32,20) used to guide the drive assembly 22 when the drive assembly reaches close to the end of the stroke. The air bearing(s) can be turned on when the drive begins to move back in the opposite direction.

More precise methods require monitoring the position of the drive assembly by a measuring means (not shown) and applying a driving force to restore and maintain the correct position. The accuracy of the measuring means need not be precise, but on the order of 0.1 to 1.0 mm. The driving force can be obtained by using another linear motor (not shown) attached to the drive assembly 22, or another motor that is coupled to the drive assembly.

Finally, the one or more air bearings (66,66A,66B) of the carrier/follower 60 can be turned off to act as a brake during idle periods of the stage 42. If the coil 68 of the

carrier/follower 60 is energized with the carrier/follower 60 in the braked condition the drive assembly will be driven and accelerated. Thus, the position control system 16 monitors the location of the drive assembly 22. When the drive assembly drifts out of position, the drive assembly is repositioned with sufficient accuracy by intermittently using the coil 68 of the carrier/follower 22.

In the first embodiment of the present invention, the driving frame 22 which functions as a counter weight is installed in order to prevent the center of the gravity of the entire system from shifting, and was made to move in the opposite direction from the stage body 42. However, when the structures in Figs. 1 - 5 are applied to a system where the shift of the center of the gravity is not a major problem, it is also acceptable to fix the driving frame 22 on the base structure 12 together. In that case, except for the problem regarding the center of the gravity, some of the effects and function can be applied without making any changes.

This invention provides a stage which can be used for high accuracy position and motion control in three degrees of freedom in one plane: (1) long linear motion; (2) short linear motion perpendicular to the long linear motion; and (3) small yaw rotation. The stage is isolated from mechanical disturbances of surrounding structures by utilizing electro-magnetic forces as the stage driver. By further using a structure for this guideless stage, a high control bandwidth is attained. These two factors contribute to achieve the smooth and accurate operation of the stage.

<u>Description of the Preferred Embodiment</u>

Bearing in mind the description of the embodiment illustrated in Figs. 1-6, the preferred embodiment of the present invention is illustrated in Figs. 7 and 8 wherein the last two digits of the numbered elements are similar to the corresponding two digit numbered elements in Figs. 1-5.

In Figs. 7 and 8, differing from the previous first embodiment, the driving frame which functions as a counter weight is removed, and each of the magnet tracks 156A and 156B of the two linear motors is rigidly mounted onto the base structure 112. The stage body 143 which moves straight in the X direction is placed between the two magnetic tracks 156A and 156B. As shown in Fig. 8, an opening 112B is formed in the base structure 112, and the stage body 142 is arranged so as to straddle the opening part 112B in the Y direction. There are four pre-loaded air bearings 148 fixed on the bottom surface at both ends of the stage body 142 in the Y direction, and they buoy up and support the stage body 142 against the base surface 112A.

Furthermore, according to the present embodiment, the reticle 144 is clamped and supported on the reticle chuck plate 143 which is separately placed on the stage body 142. The straight mirror 150Y for the Y axis laser interferometer and two corner mirrors 150X1, 150X2 for the X axis laser interferometer are mounted on the reticle chuck plate 143. The driving coils 154A and 154B are horizontally fixed at the both ends of the stage body 142 in the Y direction with respect to the magnetic tracks 156A and 156B, and due to the control subsystem previously described, make the stage body 142 run straight in the X direction and yaw only to an extremely small amount.

As evident from Fig. 8, the magnetic track 156B of the right side of the linear motor and the magnetic track

156A of the left side of the linear motor are arranged so as to have a difference in level in z direction between them. In other words, the bottom surface of the both ends in the direction of the long axis of the magnetic track 156 on the left side is, as shown in Fig. 7, elevated by a certain amount with a block member 155 against the base surface 112A. And the carrier/follower 160 where the VCM is fixed is arranged in the space below the elevated magnetic track 156A.

The carrier/follower 160 is buoyed up and supported by the pre-loaded air bearings 166 (at 2 points) on the base surface 112A' of the base structure 112 which is one level lower. Furthermore, two pre-loaded air bearings 164 against the vertical guiding surface 117A of the straight guiding member 117, which is mounted onto the base structure 112, are fixed on the side surface of the carrier/follower 160. This carrier/follower 160 is different from the one in Fig. 4A according to the previous embodiment, and the driving coil 168 (Fig. 7) for the carrier/follower 160 is fixed horizontally to the part which extends vertically from the bottom of the carrier/follower 160, and positioned in the magnetic flux slot of the magnetic track 156A without any contact. The carrier/follower 160 is arranged so as not to contact any part of the magnetic track 156A within the range of the moving stroke, and has the VCM 170 which positions the stage body 142 precisely in the Y direction.

Furthermore, in Fig. 7, the air bearing 166 which buoys up and supports the carrier/follower 160 is provided under the VCM 170. The follow-up motion to the stage body 142 of the carrier/follower 160 is also done based on the detection signal from the position sensor 13 as in the previous embodiment.

In the second embodiment structured as above, there is an inconvenience where the center of the gravity of the entire system shifts in accordance with the shift of the stage body 142 in the X direction, since there is substantially no member which functions as a counter weight. It is, however, possible to position the stage body 142 precisely in the Y direction with non-contact electro-magnetic force by the VCM 170 by way of following the stage body 142 without any contact using the carrier/follower 160. Furthermore, since the two linear motors are arranged with a difference in the level in the Z direction between them, there is a merit where the sum of the vectors of the force moment generated by each of the linear motors can be minimized at the center of the gravity of the entire reticle stage because the force moment of each of the linear motors substantially cancels with the other.

Furthermore, since an elongated axis of action (the line KX in Fig. 4B) of the VCM 170 is arranged so as to pass through the center of the gravity of the entire structure of the stage not only on the XY plane but also in the Z direction, it is more difficult for the driving force of the VCM 170 to give unnecessary moment to the stage body 142. Furthermore, since the method of connecting the cables 82, 83 via the carrier/follower 160 can be applied in the same manner as in the first embodiment, the problem regarding the cables in the completely non-contact guideless stage is also improved.

The same guideless principle can be employed in another embodiment. For example, in schematic Figs. 9 and 10, the stage 242, supported on a bases 212, is driven in the long X direction by a single moving coil 254 moving within a single magnetic track 256. The magnetic track is

rigidly attached to the base 212. The center of the coil is located close to the center of gravity of the stage 242. To move the stage in the Y direction, a pair of VCM's (274A,274B,272A,272B) are energized to provide an acceleration force in the Y direction. To control yaw, the coils 274A and 274B are energized differentially under control of the electronics subsystem. The VCM magnets (272A,272B) are attached to a carrier/follower stage 260. The carrier/follower stage is guided and driven like the first embodiment previously described.

This alternative embodiment can be utilized for a wafer stage. Where it is utilized for a reticle stage the reticle can be positioned to one side of the coil 254 and track 256, and if desired to maintain the center of gravity of the stage 242 passing through the coil 254 and track 256, a compensating opening in the stage 242 can be provided on the opposite side of the coil 254 and track 256 from the reticle.

Merits gained from each of the embodiments can be roughly listed as follows. To preserve accuracy, the carrier/follower design eliminates the problem of cable drag for the stage since the cables connected to the stage follow the stage via the carrier/follower. Cables connecting the carrier/follower to external devices will have a certain amount of drag, but the stage is free from such disturbances since there is no direct connection to the carrier/follower which acts as a buffer by denying the transmission of mechanical disturbances to the stage.

Furthermore, the counter-weight design preserves the location of the center of gravity of the stage system during any stage motion in the long stroke direction by using the conservation of momentum principle. This apparatus essentially eliminates any reaction forces

between the stage system and the base structure on which the stage system is mounted, thereby facilitating high acceleration while minimizing vibrational effects on the system.

In addition, because the stage is designed for limited motion in the three degrees of freedom as described, the stage is substantially simpler than those which are designed for full range motions in all three degrees of freedom. Moreover, unlike a commutatorless apparatus, the instant invention uses electromagnetic components that are commercially available. Because this invention does not require custom-made electromagnetic components which become increasingly difficult to manufacture as the size and stroke of the stage increases, this invention is easily adaptable to changes in the size or stroke of the stage.

The embodiment with the single linear motor eliminates the second linear motor and achieves yaw correction using two VCM's.

While the present invention has been described in terms of the preferred embodiment, the invention can take many different forms and is only limited by the scope of the following claims.

Claims

1. An object moving apparatus which includes a first movable member for moving linearly at least in a first direction on a reference surface of a base structure, said apparatus comprising:

(a) a first fluid bearing system for suspending said first movable member from said reference surface;

(b) a guide member mounted on said base structure, which includes a guiding surface elongated in the first direction for constraining a direction intersecting the first direction;

(c) a second movable member located adjacent the side of the first movable member, which is capable of moving in the first direction by conforming with said reference surface and said guiding surface;

(d) an electromagnetic linear driving system disposed between said first and second movable members, said system including a first magnetizing member mounted on said first movable member and a second magnetizing member mounted on said second movable member in order to generate a driving force toward the first direction; and

(e) a second fluid bearing system for suspending said second movable member from said reference surface independently from said first movable member and for engaging said guiding surface keeping a space between said first and second magnetizing members;

wherein said first and second movable members are reversely moved in the first direction by energizing said electromagnetic linear driving system.

2. Positioning apparatus comprising:

a stage;

a base structure;

a carrier/follower;

first electromagnetic means of a commutated nature supported on said base structure for magnetically positioning said stage, said first means being capable of moving said stage in a first linear direction;

second electromagnetic means supported on said carrier/follower for magnetically positioning said stage, said second means being capable of moving said stage in a second linear direction substantially orthogonal to said first linear direction for small displacements in said plane;

yaw correcting means for correcting small rotation in a plane using the said first or second electromagnetic means;

positioning means for positioning said carrier/follower in said first linear direction;

means for sensing the position of said stage in said first linear direction and outputting a corresponding signal to said positioning means; and

means for controlling the position of said carrier/follower to follow the approximate position of said stage in said first linear direction,

3. The positioning apparatus of claim 2 wherein said stage includes a pair of opposed sides and said first electromagnetic means includes a pair of drive assemblies, said drive assemblies positioned respectively at said opposed sides of said stage, each of said drive assemblies including a coil member and a magnet member with one of said members fixedly mounted on said stage and the other of said members movably mounted on said base structure whereby said drive assemblies can apply an action force to said

stage to move said stage.

4. The positioning apparatus of claim 3 wherein said movable member can move in response to a reaction force to substantially maintain the centre of gravity of the apparatus.

5. The positioning apparatus of claim 3 or 4 in which said yaw correcting means includes control means for driving each of said pair of drive assemblies by a different amount.

6. A positioning apparatus comprising, in combination:

a stage having a pair of opposed sides;

a carrier/follower;

first electromagnetic commutated means for magnetically positioning said stage and including at least one linear drive means for driving said stage in one linear direction;

second electromagnetic means mounted on said carrier/follower for moving said stage small distances in said plane substantially orthogonal to said one linear direction; and

means for controlling the position of said carrier/follower to follow the approximate position of said stage in said one linear direction.

7. The positioning apparatus of claim 6 including a base structure and wherein each of said linear drive means includes a coil member and a magnet member with one of said members fixedly mounted on said stage and the other of said member movably mounted on said base structure whereby said drive assemblies can apply an action force to said stage to move said stage.

8. The position apparatus of claim 7, wherein said movable member can move in response to a reaction force to substantially maintain the centre of gravity of the

apparatus.

9. The positioning apparatus of claims 6, 7 or 8, including a base structure and means for suspending said stage above said base structure.

10. The positioning system of claim 9 including positioning means mounted on said base structure for positioning said carrier/follower in said one linear direction.

11. The positioning apparatus of any of claims 2 to 10 wherein second electromagnetic means includes at least one voice coil motor.

12. The positioning apparatus of any of claims 2 to 10 wherein said second electromagnetic means includes at least a pair of voice coil motors and said yaw correcting means includes control means for driving each of said pair of voice coil motors by a different amount.

13. The positioning apparatus of any of claims 2 to 12 wherein said first electromagnetic means includes one drive assembly including a coil member and a magnet member with at least one of said members fixedly mounted on said stage and said second electromagnetic means includes a plurality of voice coil motors.

14. Positioning apparatus comprising:

a stage having a pair of opposed sides;

a base structure;

means for suspending said stage above said base structure;

a driving frame;

a carrier/follower;

first electromagnetic means of a commutated nature mounted on said base structure for magnetically positioning said stage, said first means being capable of moving said stage in a first linear direction and in a small yaw rotation in a plane;

said first electromagnetic means including a pair of drive assemblies, said drive assemblies positioned respectively at said opposed sides of said stage;

each of said drive assemblies including a coil member and a magnet member with one of said members fixedly mounted on said stage and the other of said members mounted on driving frame;

second electromagnetic means mounted on said carrier/follower for magnetically positioning said stage, said second means being capable of moving said stage in a second linear direction perpendicular to said first linear direction for small displacements in said plane;

positioning means mounted on said base structure for positioning said carrier/follower in said first linear direction;

means mounted on said base structure for sensing the position of said stage in said first linear direction and outputting a corresponding signal to said positioning means; and

means for controlling the position of said carrier/follower to follow the approximate position of said stage in said first linear direction.

15. The positioning apparatus of claim 14 including means for driving said carrier/follower from one of said members of one of said drive assemblies.

16. The positioning apparatus of claim 14 or 15 including means for suspending said driving frame above said base structure whereby said drive assemblies can apply an action force to said stage to move said stage and said movable driving frame can move in response to a reaction force to substantially maintain the center of gravity of the apparatus.

17. A stage apparatus which includes a base structure having a reference surface and a main stage body supported on the reference surface through a gas bearing to move linearly at least in a first direction, said apparatus comprising:

(a) a frame assembly including two main arm members elongated in the first direction and parallel with each other,

(b) means for supporting said frame assembly on the reference surface of said base structure through a gas bearing independently from said main stage body;

(c) a guide member formed on a portion of said base structure, for guiding the movement of said frame assembly in the first direction;

(d) two linear motors which respectively include a magneto track mounted linearly in each of said main arm members and a coil member mounted at each of opposite sides of said main stage body to be located respectively in the magnetic flux of said magneto track;

(e) a drive control system for energizing each of said coil members simultaneously to move said main stage body and said frame assembly reversely in the first direction on the reference surface;

(f) a movable follower member for following said main stage body in the first direction by conforming with said guide member to cause it to maintain a predetermined spatial distance from said main stage body; and

(g) an electromagnetic actuator for positioning said main stage body in a second direction perpendicular to the first direction inside of said frame assembly while keeping a space between said magneto track and said coil member, respectively, and thereby producing a magnetic force between said main stage body and said movable follower member in the second direction.

18. The stage apparatus of claim 17 wherein said frame assembly is rectangular and includes two connecting arms connecting end portions of said two main arm members and with said main stage body located between said two main arm members.

19. A stage apparatus providing a first movable member which is supported on a reference surface of a base

structure through a fluid bearing and capable of linearly moving at least in a first direction, said apparatus comprising:

(a) two electromagnetic linear driving sources elongated in a first direction parallel each other such that said first movable member is located therebetween,

each of said two driving sources including a first magnetizing member mounted on said first movable member and a second magnetizing member elongated in the first direction for interacting magnetically with said first magnetizing member;

(b) an installing member for locating said two second magnetizing members with a predetermined space in a second direction perpendicular to the first direction;

(c) a linear guide portion formed on said base structure elongated in the first direction;

(d) a movable follower member for following said first movable member in the first direction by conforming with said linear guide portion to cause it to maintain a predetermined spatial distance from said first movable member;

(e) a non-contact type actuator for generating attraction and repulsion between said first movable member and said movable follower member to move said first movable member in the second direction; and

(f) a control system for energizing said two linear driving sources and said non-contact type actuator to position said first movable member in the second direction while moving said first movable member toward the first direction.

20. A stage apparatus according to claim 19, wherein said installing member is connecting parts for fixing each of said two second magnetizing members on said base structure.

21. A stage apparatus according to claim 19 or 20, wherein said installing member is a rectangular frame assembly movable in the first direction.

22. A movable stage apparatus which includes a movable member suspended on a referenced surface of a base structure through a fluid bearing system and moving linearly at least in a first direction on the reference surface, said apparatus comprising:

(a) at least one electromagnetic linear driving source elongating in the first direction, said driving source including a first magnetizing member mounted on said movable member and a second magnetizing member mounted on said base structure along the first direction to interact magnetically with said first magnetizing member;

(b) a linear guide portion formed on said base structure along the first direction;

(c) a follower member for following said movable member in the first direction by conforming with said linear guide portion to maintain a predetermined spatial distance from said movable member; and

(d) at least one non-contact type actuator for generating attraction and repulsion between said movable member and said follower member to move said movable member in a second direction perpendicular to the first direction keeping a space between said first and second magnetizing members.

23. A movable stage apparatus as claimed in claim 22, comprising:

two electromagnetic linear driving sources elongating in the first direction parallel to each other such that said movable member is located there between.

24. A movable stage apparatus as claimed in claim 22 or 23, comprising at least two non-contact type actuators

25. An object moving apparatus, positioning apparatus or stage apparatus substantially as described herein with reference to Figures 1 to 6, Figures 7 and 8, or Figures 9 and 10 of the accompanying drawings.

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Patents Act 1977 Ex- -iner's report to the Comptroller under Section 17 (Th- Search report)	Application number GB 9512659.5
Relevant Technical Fields .) UK Cl (Ed.N) H1K-KMBY; G2A-AAN, AEAA (ii) Int Cl (Ed.6) H01L-21/00; G03F-7/20	Search Examiner S J DAVIES Date of completion of Search 12 SEPTEMBER 1995
Databases (see below) (i) UK Patent Office collections of GB, EP, WO and US patent specifications. (ii) ONLINE WPI	Documents considered relevant following a search in respect of Claims :- 1

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Category	Identity of document and relevant passages	Relevant to claim(s)
A	EP 0502578 A1 (PHILIPS) see eg Figures 1-3	
A	US 5285142 (GALBURT et al) see eg Figure 1	

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